

Analysis of Engine Thermal Effect on Electronic Control units for “Robot Fleets for Highly effective Agriculture and Forestry Management” (RHEA)

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Abstract: The procedures carried out in order to perform the analysis by engine thermal effect on the electronic control units installed on a ground robot fleet were studied in this work. The objective is to characterize the temperatures on the engine tractor environment for different tasks. In this way, it could be possible to estimate the environmental conditions that the cabinets will be exposed to. Those cabinets, in which the electronic controls of sensors, actuators and power supplies will be stored, will be located aboard the ground robot units.

1. Introduction

Within the European project "Robot Highly Effective Fleets for Agriculture and Forestry Management" (project n ° 245986 of the 7th framework program), defined by the acronym "RHEA", it is intended to carry out the development of a structure in order to store all the electronic boxes of the devices that will be assembled in the ground robot (sensors, communication systems and actuators).

In this work we face firstly the identification of the heat emissions sources on the vehicle, and then the different ways for measuring emissions of heat, as well as the important influence of temperature on electronic devices. As a second step, an experiment was defined and performed to assess the environment of the structure. Several remarks on the results and conclusions are provided for the implementation of the structure in the near future.

1.1 Heat emission of tractors and agricultural vehicles

Any object with a temperature above absolute zero emits energy as an electromagnetic emission. As its temperature rises, the energy emission also increases. All mechanical systems generate thermal energy during normal

operation which could be used to evaluate their operating condition. One of the biggest problems in mechanical systems is due to excessive temperatures. This excessive heat can be generated by friction, cooling degradation, material loss or blockages. An excessive amount of friction can be caused by wear, misalignment, over or under lubrication and misuse.

In relation with the internal combustion engines, it is difficult to reach a maximum efficiency higher than 42%, so large amount of wasted fuel energy is expelled from the engine to the surroundings as heat in several ways, with a significant fraction through the exhaust. A recent study estimated that in a typical 2 l gasoline engine used on passenger cars, 21% of the released energy is wasted through the exhaust at the most common load and speed condition. Current estimates of waste thermal energy from light-duty vehicle systems range from 20 kW to 400 kW, depending on engine size and engine torque-speed conditions. (Wang et al., 2011)

1.2 Measurement of heat emissions

Mobile agricultural machines are becoming more complex due to the combination of work steps and the implementation of systems for additional processing (Kutzbach, 2000). Nowadays, the detection of unusual events and diagnosis of its casual origin are still performed by human operators. This higher complexity and the multivariate character of agricultural machinery processes implies an overload for the operator thus highlighting the need for the introduction of fault detection and diagnostic systems on agricultural machinery processes (Craessaerts et al., 2010)

Fault diagnostic systems have not been given much attention yet in agricultural machinery research. However, these techniques could be of high value at a supervisory control level for agricultural machinery (Craessaerts et al., 2010).

There are dozens of predictive maintenance technologies, and some have become a standard in many industries. The 'standard' technologies include vibration analysis, ultrasound, oil analysis, wear particle analysis and thermography (Girdhar, 2004).

In the recent past, various techniques have been developed for studying the thermal aspects of machining and are broadly classified into two, namely, (1) the experimental approach and (2) the numerical approach. With the recent developments in machining automation, various cutting temperature measurement techniques, including tool-work thermocouple, embedded thermocouple, and infrared pyrometer, emerged (Rai and Xirouchakis, 2008).

Literature reveals that the previous experimental techniques have been widely applied in the turning process due to its simplicity. Since it is also tedious to calculate directly the temperatures of some tool-work interface, the inverse heat transfer method was employed for estimating the transient tool-face temperature

and heat dissipation. Recently, various finite-element method (FEM) and finite-difference method (FDM) based numerical models have also been proposed for the determination of the temperature distribution in the workpiece, which were difficult to study by experimental methods (Rai and Xirouchakis, 2008).

1.3 Effect of heat on the electronics

Electronic devices have been developed with a trend toward higher performance and smaller dimensions. These electronic devices normally contain a fairly high energy density.

The reliability of an electronic component is defined as the ability of performing required function under given conditions for a stated time. An electronic device fails to fulfil its intended function when its application or environmental condition exceeds its application limit. A survey from the U.S. Air Force indicates that the percentage of temperature related failures in electronics exceeded 55%. This high percentage evidences that the current cooling methods are inadequate to fulfil the device cooling requirement. Advances in electronic packaging and increases in chip complexity and functionality are responsible for this high percentage. Theoretically, electronic components are very reliable at recommended operating temperatures. However, environmental factors and unusual operating situations greatly decrease the effective operating time (Alawadhi and Amon, 2003). Mithal (1996) studied the effect of temperature on electronic component reliability. The experimental results indicate that a 1 °C decrease in a component temperature may lower its failure rate by as much as 4%. Moreover, the research indicates that a 10 °C to 20 °C increase in component temperature may increase its failure rate by 100%.

When considering electric motors and generators, operating temperatures and thermal patterns can be a valuable key in a predictive maintenance program. All motors have a normal thermal pattern as well as given maximum operating temperature. This temperature is usually stated on the nameplate of the motor and is normally given as a rise in Celsius degrees above the ambient air temperature. Most motors are designed to operate at ambient temperatures that do not exceed 40 °C. Conditions such as inadequate air flow, partial discharge, unbalanced voltage, bearing failure, insulation failure and degradation in the rotor or stator can be identified with a temperature monitoring program. Abnormal thermal patterns can also identify misalignment in couplings when these devices are used in conjunction with motors (Peterson, 2008).

2. Materials and methods

At this point, it comes to specifying the issues in relation to the test conducted for this work. The materials used in order to carry out the analysis of thermal effects derived from the tractor engine on electronic control units are defined below. In turn, the paper also explains the methodology undertaken for the completion of this analysis.

2.1 Tractor

The tractor used during the course of this study consisted of a New Holland tractor "TN70VA" whose characteristics, shown in the table below, were comparable to the tractor "T3050 CVT" that will be used in RHEA project.

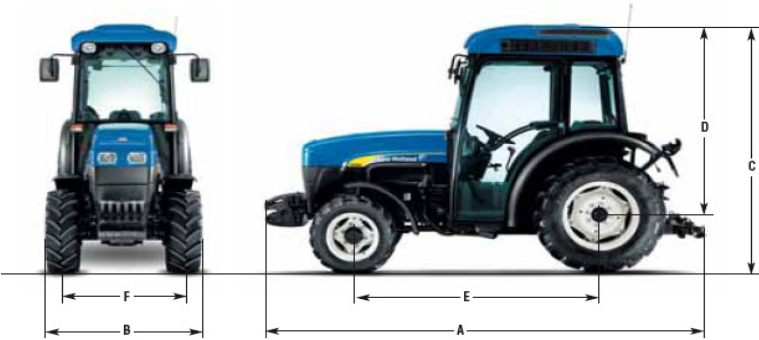


Fig.1. Front and side view of the "TN70VA" tractor

Table 1. "TN70VA" tractor dimensions

Dimensions	
A Total length including pack and rear linkage (mm)	3663
B minimum width (mm)	986
C Total height (mm)	2260
D Height from center of rear axle to top of cab (mm)	1798
E Wheelbase: ST/DT (mm)	2035 / 2064
F width via	
• Front ST min-max/DT min-max (mm)	838 – 1166 / 835 – 1049

2.2 Structure

On the tractor mentioned above, the installation of plates took place, in order to simulate the cabinets’ structure, which will be responsible for housing the electronic equipment from the sensors, communication devices, as well as the actuation systems developed for the RHEA project.

The structure consisted of two aluminium plates (100x20 cm) at different heights, joined by profiles for each of the sides. At the same time the profiles of both sides were joined by a transverse profile, providing rigidity to the structure.

The temperature sensor cards were attached to register the temperature in the environment of the assembled framework.

2.3 Temperature sensor cards

The temperature sensor cards used were Turbo Tag Cards ® “T702-B”, (Sealed Air, USA) (Figure 2), which were designed to obtain accurate and efficient data using a radio frequency (RF) communication system. Each card (characteristics shown in Table 2) had an accuracy of $\pm 0.5^{\circ}\text{C}$ throughout the operation range. Its data storage limit was an archive file of up to 702 measurements, with a size of a credit card.

Table 2. Specifications of TurboTag ®, “T702-B”

Number of measures:	702
Temperature range:	-55°C to +80°C (-67F to +176F)
Temperature accuracy:	+/- 0.5°C (+/- 0.9 F) with calibration accuzone™ (95%)
Control space of time:	20 minutes minimum, 3 months maximum
Delay control:	0 minutes minimum, 21 days maximum
Rfid interface:	13.56 MHz passive – according to ISO 15693-3
Rfid reading distance:	1 to 30 centimetres (greater distance with antenna booster)
Time data capture:	Less than 2 seconds
Alarms:	High and low alarms set by the user / store time above / below
Means:	Store temperature or mkt arithmetic mean (geometric mean)
Uhf:	Holds 24-character code epc (uhf reader or manually)
Software registration:	Session manager™ software creates files and / or database records
Lifetime parameters:	Stores the temperature sensitivity based on Arrhenius kinetic model
Lifetime:	Provides remaining information of lifetime at the point of reading

In total, the installation consisted of 69 temperature cards throughout the aluminium structure (Fig. 2).



Fig.2. Turbo Tag® card and framework with all Turbo Tag® cards installed

2.4 Tasks performed

Once the temperature sensors in the structure were installed, and it was joined to the tractor, we proceeded with the development of the tests. These consisted on performing two clearly differentiated tasks, allowing an environmental study of the engine for different conditions.

The tasks performed during the test, which took place in the experimental field of the UPM EIA (4477224.73 m N and 437398.95 m E UTM coordinates), were as follows:

Tillage tasks by using a rotator tiller implement that requires connection to the PTO. The task was carried out on a plot of one third of hectare (Figure 3).

Transport task of a water tank for irrigation of the trees in the UPM EIA’s experimental field. In this case a connection to the PTO it was not required (Figure 3).

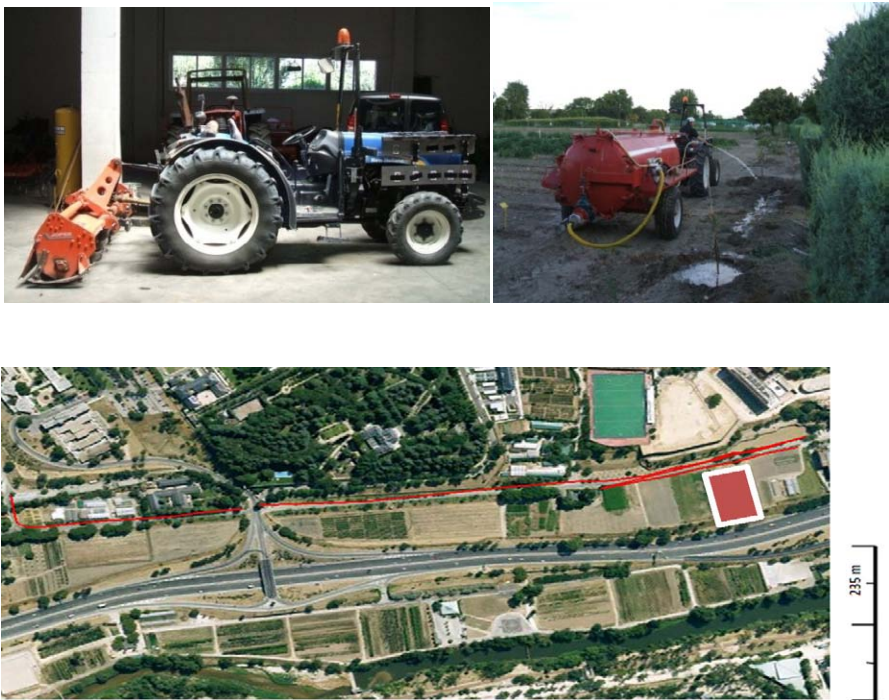


Fig.3. Rotovator task (top left); Irrigation task (top right) and task performed by the tractor during the test (below): red square represent the rotovator tasks and red line the irrigation task

2.5 Principal points of interest

From all points sensed by the installation of the Turbo Tags in the structure, it was interesting to consider which would be the main points of interest. On this line, it was studied both the engine air inlet and the engine air outlet (Figure 4).



Fig.4.Engine air inlet (blue circumference), engine air outlet (red circumference) and longitudinal and height heat distribution (by red ellipse representing expected warmer places and by blue ellipse the least)

At the same time, were considered as special areas of interest, those which allowed obtaining the distribution of heat within the structure, both longitudinal, lateral and in height (Fig. 4.). The highest temperature was expected in the outlet of the

engine cooling air. Thus, it is expected that the temperature would decrease as moving away from this point.

Thus, the sensor cards that would best represent the main points to consider (outlet and inlet of air into the engine and heat distribution) were differentiated by different colour circumferences in the Fig 5.

The circumference colour represented in each of the selected cards denoted a location in the structure, being the same location for same colour (eg. with red the position of the outlet of the engine air; with grey the inlet of the engine air ...)

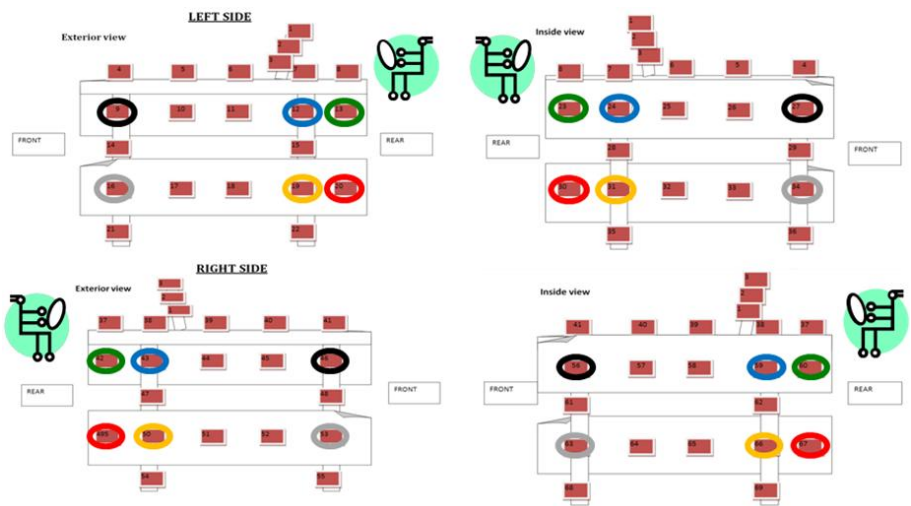


Fig.5. Longitudinal and height heat distribution (by red representing expected warmer places and by blue the least

3. Results

The results obtained during the test for different tasks performed by the tractor show the values recorded by the selected cards. For this purpose the values for each of selected cards were plotted using the representative colour of that location.

3.1 Rotovator test

From rotovator results (Fig. 6), it was observed that lateral factor becomes an important parameter, and at red location (next to the engine air outlet), the higher temperatures were reached on the left side.

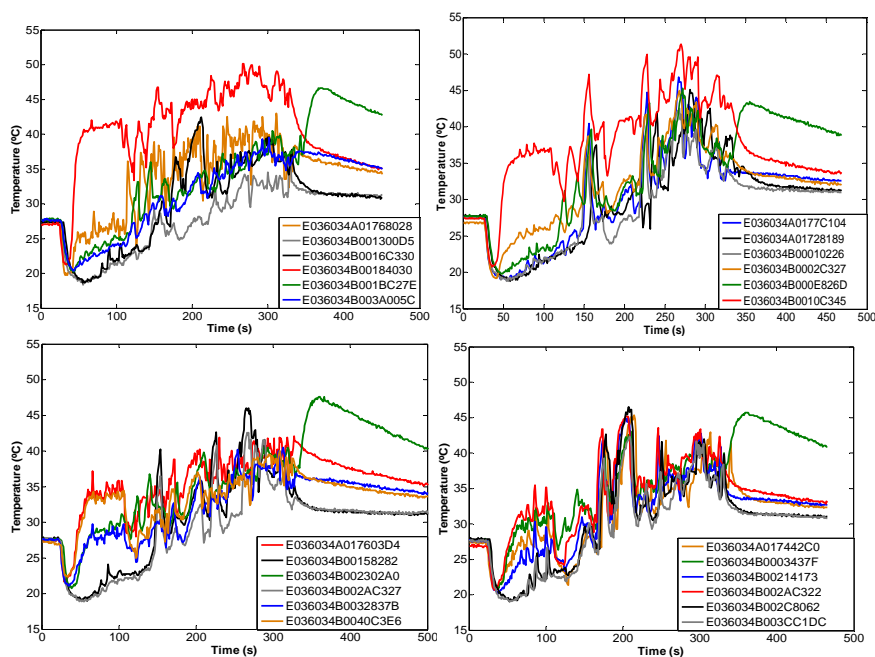


Fig.6. Temperature recorded during rotovator task in the internal left side (above left); external left side (above right) internal right side (bottom left); and external right side (bottom right) of the structure.

3.2 Irrigation test

Similarly, data obtained during irrigation are shown in the following graphs (Fig. 15-18). In such graphs it can be observed, as mentioned for the rotovator results, that: the lateral factor becomes important, and higher temperatures appear on the left side.

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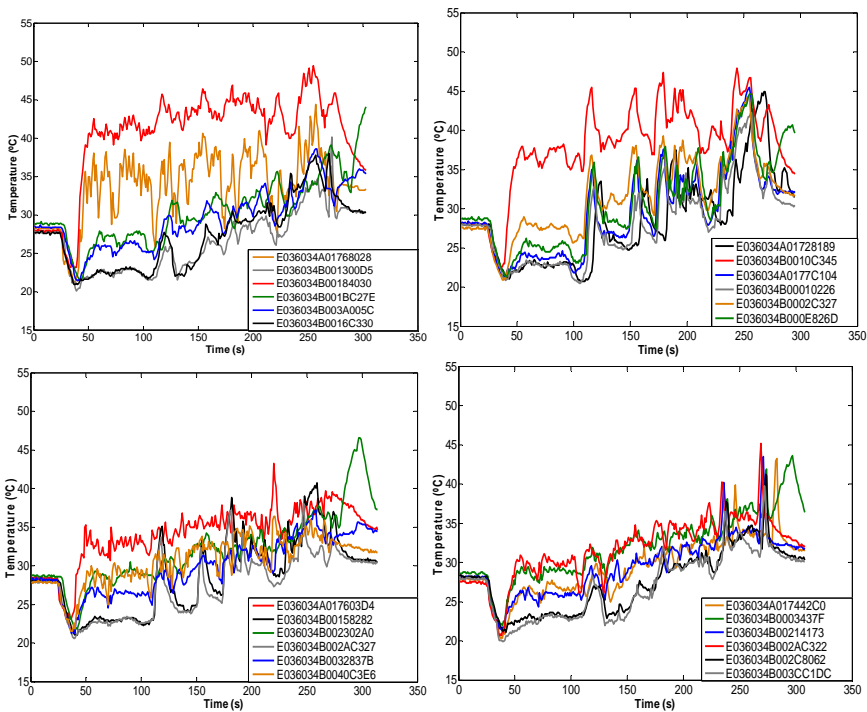


Fig.7. Temperature obtained during irrigation task in the internal left side (above left); external left side (above right) internal right side (bottom left); and external right side (bottom right) of the structure.

3.3 Analysis of variance – mean temperature

An analysis of variance was performed for both mean and variance of the temperatures recorded by the cards. In table 3 the values obtained for the analysis of variance of mean temperatures and variance are shown.

The F values suggest that the most significant factors were longitudinal location (67.2), task performed (29.76), longitudinal location combined with internal or external location (17.12), and the linkage of side and longitudinal location (12, 4); being the remainder factors not significant at 5%.

Table 3. Analysis of variance of mean temperatures and variance recorded during the test.

Source	Sum Sq. (mean)	d.f.	F (mean)	Sig. level (mean)	Sum Sq. (var)	F (var)	Sig. level (var)
Task	103.124	1	29.76	***	4015.28	123.38	***
Side	5.657	1	1.63	ns	1264.61	38.86	***
Internal/External	9.031	1	2.61	ns	1134.53	34.86	***
Height	2.945	1	0.85	ns	617.9	18.99	***
Longitudinal location (front/rear)	232.907	1	67.2	***	8.3	0.26	ns
Task* Side	11.421	1	3.3	*	34.61	1.06	ns
Task* Internal/External	0.42	1	0.12	ns	40.53	1.25	ns
Task* Height	3.279	1	0.95	ns	136.83	4.2	**
Task*Longitudinal location (front/rear)	0.29	1	0.08	ns	33.79	1.04	ns
Side* Internal/External	2.377	1	0.69	ns	50.33	1.55	ns
Side*Height	29.409	1	8.49	**	39.21	1.2	0.2752
Side*Longitudinal location (front/rear)	42.991	1	12.4	***	416.35	12.79	***
Internal/External * Height	0.8	1	0.23	ns	0.31	0.01	ns
Internal/External *Longitudinal location (front/rear)	59.341	1	17.12	***	12.39	0.38	ns
Height*Longitudinal location (front/rear)	12.097	1	3.49	*	142.18	4.37	**
Error	325.78	94			3059.16		
Total	806.382	109			10845.99		

*10%; **5%; ***1%

With the aim to simplify the results, it was carried out the elaboration of 2D temperature interpolation of the average temperatures (Fig. 8).

From the figures shown below, it was observed that:

- Rotovator caused more warming, because it was connected to the PTO of the tractor and required a higher power from it.
- A higher warming is produced at the rear, where the outlet of the engine cooling was placed.
- The highest average temperature is recorded at the rear left side.
- The front of the structure showed a higher temperature for the external side compared to the internal side (solar radiation effect).
- Heat transfer and thus temperature recorded were distributed in a fan shape

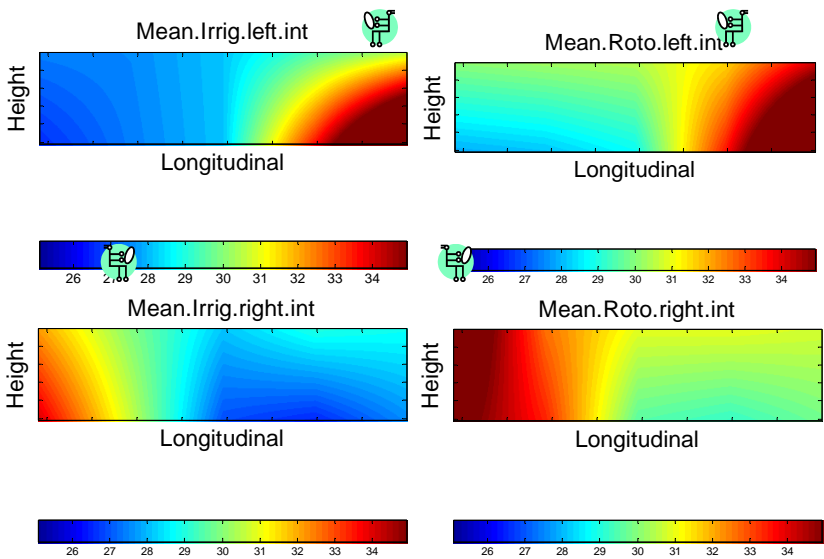


Fig.8. Interpolation of mean temperatures for each task (left figures represent irrigation task, while right figures represent rotovator task), and side (above figures represent left side, while below figures represent right side)

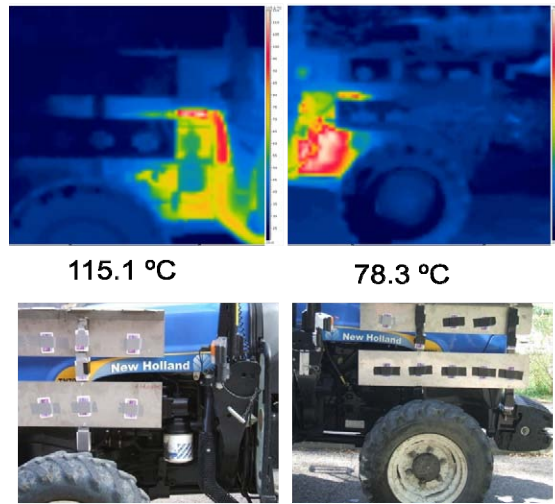


Fig.9. Infrared (FLIR i5, USA) and RGB pictures of left and right side of the tractor during irrigation task

3.4 Analysis of variance – variance of temperature

In the same way as for average temperatures, an analysis of variance of temperatures (table 3) was elaborated. In this case the most significant factors were task various performed (123.38), side (38.86), orientation (34.8), height (18.99) and the linkage of side and longitudinal location (12.79), being the remainder factors not significant at 10%.

Besides, 2D interpolations for each task and side of the interior of the structure were developed (Fig. 10).

So, it was observed that:

- A pattern for each side existed, observing that for different tasks, the pattern of variation was the same.
- The task performed by the tractor generates a higher variation (rotovator task) or lower (irrigation task) of this pattern.
- The rear left side shows higher variations in temperature (at the same place where the mean temperature was higher).
- Greater fluctuations in temperature were produced for the upper, than for lower height; and for external than internal orientation (sensitive to the weather conditions variations).

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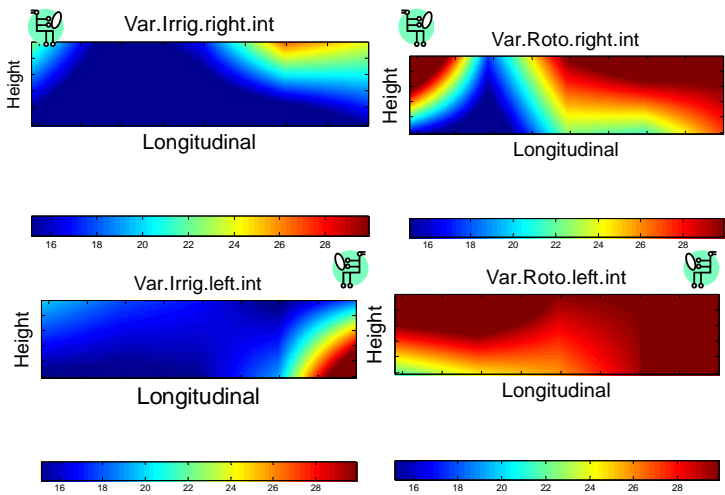


Fig.10. Interpolation of temperatures variance ($^{\circ}\text{C}^2$) for each task (left figures represent irrigation, while right figures represent rotovator task), and side (above figures represent left side, while below figures represent right side)

3.5 Cabinets’ structure applications

With the purpose to apply the knowledge acquired during the course of this test to the cabinets’ structure development, which will be responsible for housing both electronic equipment from the sensors, communication devices, as well as the performance systems , it could be said that:

The cabinets’ sensitive part of the structure (sensors and others devices) will be placed on the right side of the tractor. Also it will be important to move down a position the DGPS receiver box, leaving free the point of greatest thermal variations.

The cabinets’ disturbing part (power supply and actuators) will be placed on the tractor left side, but displacing the power supply position to the front, as this will be the equipment that release more heat.

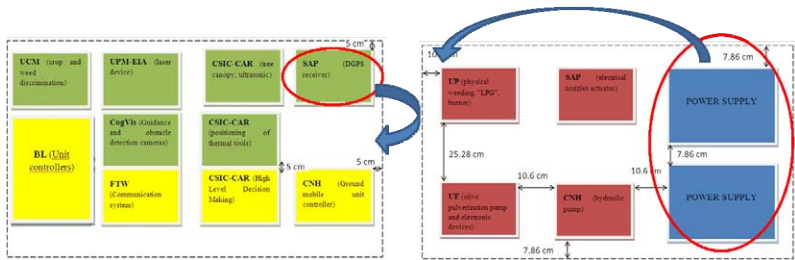


Fig. 11. Representation of the components placed at cabinets’ structure, as well as changes in location to be considered after this test

4. Conclusions

It would be desirable to locate the electronic devices that have a greater sensitivity to temperature and temperature variation, as far as possible from components located on the rear left side of the tractor used during this test (hydraulic oil filter, exhaust gas ...).

It will be advisable to conduct a similar test in winter, where the effect of solar radiation will be reduced.

Even though temperatures above 50 °C have not been recorded, without taking into account the warming that will produce the electronic boxes, it will be advisable to install a cooling system that attenuates thermal effects, and decreases the possible effect on electronics failure.

Acknowledgement

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